

Formation of Gaseous Shells

F. Combes and V. Charmandaris

*DEMIRM, Observatoire de Paris, 61 Av. de l'Observatoire, F-75 014,
 Paris, France*

Abstract. HI observations have revealed in several shell galaxies the presence of gaseous shells slightly displaced from the stellar shells radially, in the outward direction. We propose a mechanism to form this gaseous shells, based on the well-known phase-wrapping process of the companion matter in a merger, with nearly radial orbits. The mechanism relies on the existence of a clumpy interstellar matter, and on dynamical friction experienced by the companion core.

1. The Problem

Shells are sharp-edged features, formed during interactions and mergers, through phase-wrapping of debris (Quinn 1984, Dupraz & Combes 1986, Hernquist & Quinn 1989). Recent HI observations have revealed the existence of associated gaseous shells, slightly displaced from the stellar ones, questioning the validity of the phase-wrapping mechanism (Centaurus A: Schiminovich et al 1994; NGC 2865: Schiminovich et al 1995; NGC 1210: Petric et al 1997). An intriguing result is that the HI shells follow the curvature of the stellar shells, but are shifted about 1kpc outside.

There are two ways shells can be formed: **-(1)-** in minor mergers, shells correspond to phase-wrapping of the stars liberated from the small companion (e.g. Quinn 1984); **-(2)-** in major mergers, shells correspond to phase-wrapping of the debris falling back into the merged-object potential (Hernquist & Spergel 1992, Hibbard & Mihos 1995). But what is the fate of gas? due to dissipation, it falls towards the center, as in the simulations of Weil & Hernquist (1993), and there should not exist gaseous shells.

2. Solution Proposed

There exists a population of small and dense gas clouds, that have very low dissipation. This gas has a behaviour intermediate between stars and diffuse gas, and remains available to form shells. Already Kojima & Noguchi (1997) have simulated the sinking of a disk satellite into an elliptical, with a sticky particle code, instead of SPH, and found no segregation between gas and stars. We have also simulated the phenomenon, with a cloud-cloud collision code, to be able to control the dissipation rate.

With strong dissipation, the gas component, after a few oscillations back and forth in the primary's potential, settles in the center, as previously. But with small dissipation, only a small fraction of the gas falls into the potential well, most of it form shells (cf figure 1).

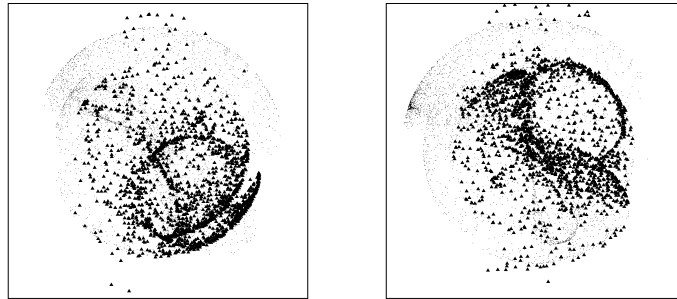


Figure 1. Simulations of the infall of a small spiral satellite into a giant elliptical, with low dissipation gas, and dynamical friction taken into account. The stars are black triangles, and gas clouds, dots.

Now it is necessary to explain the spatial displacement between the gaseous and stellar shells. Two possibilities could be tested: **-(1)-** the gas in the companion is not as bound, and does not occupy the same region initially, being in the outer parts of the galaxy. We simulate this, but this results in only a very slight and negligible shift. **-(2)-** in the merging, the gas is liberated early from the companion by the tidal forces, since it is not very bound, while the stars are liberated afterwards. Through dynamical friction, the stars have therefore time to lose a lot of energy, contrary to the gas. Dynamical friction also explains the dynamical range of the shell radii (Dupraz & Combes 1987).

This second possibility accounts very well for the shift observed between HI and stellar shells, according to simulations.

3. Observations

To check the model, millimeter observations have been carried out, to detect molecular gas in shells, since the dense clumps able to form shells should be on H_2 form. This led to the surprising detection of CO with the SEST 15m-telescope in Centaurus-A shells (Charmandaris, Combes, van der Hulst 1999). There are comparable amounts of H_2 and HI gas in the shells, far away from the galaxy center (15 kpc), which is completely unusual for a normal galaxy. This is compatible with the view that the dense clumps have been dragged in the shells by the phase-wrapping mechanism, and the HI diffuse gas has been photo- dissociated from there.

References

- Charmandaris V., Combes F., van der Hulst J-M.: 1999, in prep
 Dupraz C., Combes F.: 1986, A&A 166, 53; 1987, A&A 185, L1
 Hernquist L., Quinn P.: 1989, ApJ 342, 1
 Hernquist L., Spergel D.N.: 1992, ApJ 399, L117
 Hibbard J., Mihos C.: 1995, AJ 110, 140
 Kojima M., Noguchi M.: 1997, ApJ 481, 132
 Petric A., Schiminovich D., van Gorkom J.H. et al.:1997, AAS 191, 8212
 Quinn P.J.: 1984, ApJ 279, 596
 Schiminovich D., et al.: 1994, ApJ 423, L101; 1995, ApJ 444, L77
 Weil M.L., Hernquist L.: 1993, ApJ 405, 142